mechanism — like Newtonian physics — for future understanding of all the biologically inheritable properties (including human intellect).

Any thoughts on the interactions between science and society in Japan? I have committed to help develop the initial research projects for the Okinawa Institute of Science and Technology (OIST), which is headed by Sydney Brenner as the founding president. The Okinawa islands are located at the southern tip of Japan and have all kinds of natural beauty, intrinsic history and cultures, and high human potentials. But the islands were under US military control for 27 years after the end of Word War II, and the best parts of them are still occupied by US military bases; the economy of the Okinawa islands is still heavily dependent on these military bases so that it is intrinsically weak. A key issue for the people involved in the OIST is whether science and technology can have any beneficial effects on the future life of the Okinawa people. This is a classic question, but not a theoretical one here. Within ten years, the success or the failure of OIST will be keenly judged by Okinawa people. I am therefore questioning frequently how I can contribute towards improving the lives of Okinawa people.

Any thoughts on the present career structure for scientists in Japan? Japanese universities have no incentive to recruit female or foreign faculty members. In my view, this is our biggest problem. What we need may be a drastic governmental order to change, as most of the University budget comes from the government. The Japanese people often change their minds quickly — their reluctance to change often disappears in a single day. I hope that the same will happen with this problem.

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Quick guide

Darwin's finches

Peter R. Grant and B. Rosemary Grant

Why are they Darwin's? Darwin was the first scientist to study them, and he made them famous. On his epoch-making visit to the Galápagos archipelago in 1835 he collected some specimens for museums, as did Robert FitzRoy, captain of the *Beagle*, and a couple of their shipmates. The finches became famous when Darwin wrote about them on his return to England, after they had been described as a set of unique species by the systematist John Gould. They have entered the canonical literature with some particularly evocative phrases, none more powerful than this one from Darwin: "The most curious fact is the perfect gradation in size of the beaks of the different species of *Geospiza*… Seeing this gradation and diversity of structure in one small, intimately related group of birds, one might fancy that, from an original paucity of birds in this archipelago, one species had been taken and modified for different ends". Darwin developed his ideas about modification for different ends — adaptive evolution — in his *Origin of Species by Natural Selection* (1859), and in recognition of their contribution to evolutionary biology, Percy Lowe coined the name Darwin's finches in 1936.

What is so special about them? As currently understood there are thirteen species in the Galápagos archipelago and an extra one, which Darwin knew nothing about, on Cocos island some 600 km to the north-east. The special thing about them is they provide an exceptionally clear example of adaptive radiation, moreover one that has occurred fairly recently in the last two or three million years and seems to be intact. Many species have been derived from a common ancestor and fill a variety of ecological niches. They look similar, have similar courtship displays, but do ecologically different things. The morphological trait in which they differ most is the beak: its size and its shape. These are features that can be interpreted unambiguously in terms of their functions of gathering and dealing with different food items, including nectar and pollen in flowers, insects beneath bark, snails, fruits, seeds and even, in one bizarre case, the blood of seabirds. For a biologist they provide a wonderful opportunity to trace the evolutionary course of diversification and interpret it with ecologically relevant field observations. None of the species has become extinct as a result of human activities.

What do the finches tell us about speciation? Speciation is the divergence of two populations of a single species to the point at which they are incapable of exchanging genes and producing fertile offspring. When that point is reached the two populations are referred to, unequivocally, as separate species. Darwin's finches have not reached that point as several of them are capable of exchanging genes, even though they do so rarely. Nevertheless we refer to them as separate species because they remain distinct in morphology, behavior and song, despite occasional interbreeding.

Surprisingly, hybrid offspring survive well under some circumstances, specifically when there is a rich supply of intermediate-sized seeds suitable for exploitation by birds of intermediate beak size. When they breed they backcross to one of the parental species. Which one they breed with depends on the father, because when the time comes to choose a mate they do so largely on the basis of the song they learned from their fathers.

The finches thus function as species, courtesy of the environment and a culturally inherited trait. These features tell us that, in the course of

speciation, there first arises a behavioral barrier to the exchange of genes and only later do genetic differences become so numerous or strong that fertile offspring cannot be produced. Increasingly this appears to be a general phenomenon among vertebrates.

Are Darwin's finches still evolving? An often asked question may be phrased as follows: what can be said about evolution if it all happened in the past, for surely understanding where our biological diversity came from is then a mixture of scientific inference and inspired guesswork, almost impossible to verify? Imperceptibly slow evolution encourages such skepticism. In the *Origin of Species*, Darwin wrote "We see nothing of these slow changes in progress until the hand of time has marked the lapse of ages".

In fact, numerous studies have demonstrated evolution in action, and the study of finches on the island of Daphne has contributed significantly. When the environment changes, for example when a severe and prolonged drought occurs, finches die in large numbers, not randomly but size-selectively. Large finches with large beaks have an advantage over small birds, and survive better, because they are able to crack the large seeds that are relatively common after almost all the small seeds have been consumed. When they breed the next year they produce offspring with large beaks because beak size is heritable.

This change from one generation to the next is evolution. Some time later, the environment changes again, food supply changes, the advantage shifts toward finches with small beaks and correspondingly the direction of evolution changes. The back and forth process may have a net trajectory toward large or small size, and this is where inference enters the interpretation, because persistent directional changes in structures such as bird beaks are not likely to occur so rapidly that they can be documented in a few years.

Is anything known about their genomes? Yes, not much yet, but what is known is important. A molecular genetic study has revealed one gene that plays a role in beak formation. Its product, a signaling molecule called bone morphogenetic protein 4 (Bmp4), is active during beak development to a varying degree among species of ground finches with different adult beak sizes and shapes. In the Large Ground Finch, Bmp4 is active earlier, over a larger area of the beak and at higher concentrations than in related species with smaller beaks. Experiments have shown that Bmp4 is involved in the deepening and widening of a beak.

Variation in expression of the *Bmp4* gene may thus have been the target of natural selection in part of the adaptive radiation. It is tempting to see this gene as a key determinant of the radiation — The Gene in the Beak of the Finch — but we have to realize it is only one of many involved in the coordinated development of beaks and other structures. Other genes have yet to be identified and their functions determined.

The molecular analysis of finch beaks has only just begun. In addition to this functional genetic study, molecular markers in the nuclear and mitochondrial genome have been used to estimate the phylogeny of the finches. With some exceptions they support the traditional grouping of the species on the basis of their plumage and beak characteristics. Molecular markers have also been used to track the exchange of genes between species that interbreed, albeit rarely, and the finding is dramatic. They show a pair of species on Daphne in a state of flux, at present converging genetically and morphologically, having diverged strongly in the past. This nicely captures the evolutionary dynamism that Darwin's finches display to an unusual degree.

Do they have anything to tell us about conservation? Small populations, not just of Darwin's finches, are at risk of becoming extinct for a variety of reasons, even when human activities are not involved. They may be genetically depauperate and inbred, and they may be environmentally threatened. One lesson learned from the study on Daphne Major island is that, although inbreeding may be a disadvantage, for example in the face of new threats from pathogens, inbred birds may nevertheless have high fitness. This happens when the numbers are low and the food supply is more than enough to go around, and cautions us that populations are not necessarily doomed if they are inbred.

A second lesson derives from hybridization. As the exchange of genes between species elevates the level of genetic variation in each, their future ability to cope with a changing environment may hinge upon this continued source of new genetic material. This being so, to conserve species we should maintain communities in an intact state, and this means including not just a focal species and its basic environmental needs but other species with which it might occasionally interbreed.

Where can I find out more about Darwin's finches?

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